Designing Parametric Timber

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Abstract. Non-Standard elements in architecture bear the promise of a more suitable and sustainable solutions. A new understanding of design evolves, which is focusing on relational and evolutionary approaches. Parametric design tools and computer controlled production facilitate the emerging complex spatial constructions, as they are able to imply and feedback knowledge. Whereas the story of non-standard elements and mass customization is quickly told the actual facilitation of these techniques bears a lot of unresolved questions. We undertook a design based research taking in the whole process of digital design to production of complex shaped geometry. In close cooperation with wood construction software- and machine industry we fabricated a 1:1 demonstrator showing the potential of digital wood fabrication.

Keywords: Non Standard Element digital production; CAD/CAM; Parametric design; complex geometry; industry cooperation; Case study.

Non Standard element practice

In 1993 Catherine Slessor observed, “the notion that uniqueness is now as economic and easy to achieve as repetition, challenges the simplifying assumptions of Modernism and suggests the potential of a new, post-industrial paradigm based on the enhanced, creative capabilities of electronics rather than mechanics.” This statement provides the basis for our ongoing research work on non standard elements in an architectural context. We are especially interested in ways how individual design can evolve besides the toolsets predefined patterns? Efficient and seamless processes are needed between design and production due to these tools. The actual building of 1:1 demonstrators (Figure 1) shows insights in all connected phases.
Figure Design Research Project

In his book “The Projective cast” Robin Evans (1995) points out how the development of techniques changed architecture and the space inhabited in times of Gothic and early Renaissance. Today a similar change due to the adoption of computational techniques into architectural design can be observed. The yields of digital design techniques are accompanied by a further dissolution of the link between concept, shape and production, a phenomenon Michael Speaks (2000) calls the “Dimishing of connection between form and ideology”. A possible solution is the embedding of the process parameters in the design process. Custom made parametric design tools might bear chance, as they can contain process and other external requirements as well as non-quantitative design parameters. In the projects first part we investigated how a generic design language can be established as a result of custom tool, external parameters and design intend.

Wood and its Joints

Wood is generally considered as one of the most sustainable building materials. It as well is connected to an enormous range of different ways of processing and joining. Especially the ability to easily process the joint directly from the material itself is remarkable. “The benefits of components with integrated attachments geometry are that the attachments can be designed and controlled as part of the generative process” as Larry Sass (2006) states . Based on a long tradition in the crafts wood-wood joints, especially those based on friction as dovetail joints, have advantages:
• Can be specific to certain geometrical and tectonic requirements
• Monolithic setup allows unrestricted movement
• Inherit tolerance
• High level of prefabrication
• Efficiency in assembly due self registering joints and little or less secondary elements, as screws or bolts

Precedent research has shown the advantage of implementing self registering joints that can adapt geometrically to specific local requirements in the construction (Hofer 1999, Kilian 2003, Schindler 2007, Larsen 2008). The required production capacity is given in modern highly flexible CNC wood joinery machines. They enable not only the very fast production of individualized wooden beams but as well the rational production of geometrical complex individual joints that fit with little tolerances (Figure 2).

Figure 2
The research facilitates traditional wood joints as tenons with wood peg for the construction of free form geometry.
parametric concept using CNC wood manufacturing processes was proposed (Design: Martin Tamke and Blunck & Morgen Architects Hamburg) – the research project looked at ways to explore the link between design intent, formal and special expression and the realization process.

The basic idea of the design, as shown in Figure 3, consisted of evenly divided but differently kinked beams. Looking at the overall series appearance wavelike patterns with changing transparencies and densities appear, when ever the observer moves along the facade.

**Repetition and Series**

The concept is based on the evolution of difference within a series and mass customizations potential (Osterhuis 2003). The focus of design shifts from the constitution of a solution (i.e. single elements), that already has the final overall output in terms of geometry and internal distribution of functions imbedded, towards the definition of relationships between the elements in play. Herein the difference between the elements informs a possible final geometry. As the constitution of every element may vary, the formulated overall geometry is just one out of many – solely defined by the given parameters and the setup of the internal rules of interaction, which becomes the main design task. The evolving systems oriented on a Deleuzian (Keith Ansell-Pearson 1999) understanding allow new ways to think design. It allows for the easy exploration of a multitude of design solutions. Herein the momentum of series becomes a crucial part as it inherits the moment of change allowing for evolution and adaption to different states. The drawing of difference within the series can result in gradual as well as sudden shifts. Yet unlike usual outputs of mass customization, as first seen within the work of Artists as Andy Warhol (Collings 1998) or nowadays in customer products (Reebok 2008), the elements in our design setup are allowed to shift dramatically. In addition to the examination of change over time, represented in a diagrammatic linear alignment as seen in the mapping of different states of an object due to movement of its parts by Muybridge (Clegg 2007) or Étienne-Jules Marey (1890), we were furthermore interested in topological change and its infliction with the design's overall appearance. We introduced the possibility of different densities, branching internal spaces (Figure 4), poche and openings to appear within the series.

**Parametric Model Studies**

First investigations of the design showed that it could be easily transferred into a parametric model based on the structures axis system. As the concept
consisted of only a few determining parameters it could serve as a well-defined starting point for further geometrical experimentation. The parametric model itself consisted of three nested interacting levels with individual sets of parameters (Figure 5):
- Basic layout of rails and distribution of beams
- Beam structure (represented by mid axis)
- Solid shape

The parametric model not only allowed a direct link to production in the very first design process due to the embedding of fabrication specific parameters but as well the exploration of several variations within the design until certain predefined or evolving performance parameters were met. These parameters were later defined by tectonic, material, fabrication and aesthetic considerations. The exploration was conducted in an iterative process. Every design iteration led to a physical scale model, whose constituting elements and emerging nature could be discussed. These were distilled and emphasized in the next generation of models. By doing so an individual design language could be established.

**Interfacing - Control of the system**

With a view to an intuitive handling (Burry 2005) the systems control via diagrammatic representations showed good results (called law curves in the tools underlying software package Generative Components). Whereas first models showed a direct and foreseeable reaction to changes of parameters, later ones with more and interdependent parameters showed more complex behavior (Figure 6). This led to the design of an abstract second order representation of the parameter driving law curves. This deflection showed good results, counterfeiting the fact that the addressing of specific areas and phenomena within the model became harder to predict the more parameters were in play.

**Internal behavior**

Being able to address the overall composition and inter-element behavior of the design as well as the internal properties and geometrical setup of every element offered a wide range for manipulation, such as dimension and kink. In the course of the process further shifts were introduced by the change of amount of members, tilt, density, spacing and creasing. Branching led to desired topological change. Several design iterations proved the robustness of the chosen parametric model, although the vast amount of internal calculation limited interactivity especially in the models last evolutionary step, when the formerly straight carrying rails, were transformed into three-dimensional bending curves and the beams underwent massive topological change within the series (Figure 7).
Demonstrator

Whereas the experiments in model scale served well for the setup of a parametrical model with direct link to production and the establishment of an overall design language the scaling to an architectural scale and the operation on appropriate fabrication machinery formulated the last step in the process and a prove of concept.

The formerly developed setup served as starting point for the 1:1 Demonstrator (Figure 8). In comparison to the formerly used 2D cutting devices the step into solid beams and 3 dimensional shaped geometries required more control. Therefore algorithms constructing the final geometries in real-time according local conditions have been introduced.

Generation of 2nd order geometry

In order to increase the stability of the construction diagonal beams were introduced connecting two beams at a time. Which members met where and under which angle could be adjusted parametrically. The final second order geometries derived from the given local status of the involved members (Figure 9)
**Shifting beams**
Another feature introduced was the shift of beams from one side of the structure to the other. The existing rails served therefore no longer as backside boundaries as in the initial Parking Lot project, but the rails could swing in both directions. The combination with the rails own curving resulted in the creation of openings and pockets.

**Solver algorithms**
As the underlying parametric model was based on an abstract axis system the implications with material thickness had to be taken into account. For example a solver algorithm, courtesy provided by Axel Kilian, was used to control the depth of the cutout between the rail and the beam in order to keep enough tectonic strength. (Figure 10)

**Workflow and production parameters**
As the process design (Figure 11) focused on a smooth functioning and seamless workflow, we tried to use as much existing tool as possible before writing proprietary tools. We used the wood CAM tool HSB Cad. Its function was to define the different wood-joints on the predefined beam structure and write the instructions to the wood joinery machine. A color-code, generated in the parametric modeler eased the identification of the single beams and the application of the different types of craft based joints, as notches, cuts, dovetails and rafter joints.

As the CAM program used has no build in plausibility check, it was necessary to integrate the machines limitations into the parametric model. Available tools and process able wood dimensions were given, others had to be detected in an iterative process of tests between the modeler and the machines program. Thanks to the parametric setup this process took just a few hours at the factories site.

Besides limiting values in real-time updated spreadsheets of measured values (i.e. beam length) served well as guidance for the designer in areas where too many factors interacted to find a solving formula.
Logistics and Assembly
A high degree of planning and prefabrication enabled an easy assembly process. A key factor for this endeavor was the avoiding of on construction site measuring and adjustment and the use of secondary connectors as screws. Therefore self registering and load bearing wood connectors (dovetails and tenon joints with wood pegs) were dominating. Solely the junctions between beams and rails were carried out as double cuts or notches. Machined marks served here as guidance for assembly.

The fabrication of the 65 individual wood beams (Figure 12) on the wood joinery machine took finally 4 hours. The assembly of the construction with 4 inexperienced students, which had no insights of the project beforehand and no background in crafts, took 10 hours. The sorting of the delivered pieces, the lack of precisely planned assembly process and the tilting of the construction from its lying first state into the suspension took a great amount of this time. Although some tolerances had been set to small, which made force necessary, the joints fit generally well.

Especially the introduction of the diagonal beams, had a positive effect, as they created a three point definition of the geometry, which behaved as structural self centering system.

Conclusion
The research projects output can be examined on the field of design and the field of production.
- The crucial part for the seamless process from design to production was a clearly defined structure. Strong alterations within or the introduction of new logics and topological change proved possible however time consuming.
- The process of materialization was the most time consuming part in the process. The amount of work to adopt the model especially to maintain geometrical flexibility in a new generation where sever. In a total the component based parametric model proved to be flexible and expandable.
- Interactivity was the key to the design process design. The instant change of the model due to user inputs enabled a fluid process.
- In terms of production the high amount of planning, the precision of the fabrication, the self registering system and the logical system that formed the basis of the structure enabled a fast assembly process. The chosen wood connections proved to be able to adapt to extreme geometrical situations and provided good structural strength.

Further research
Further research is necessary to find more precise data about structural strength, actual costs and assembly within the chosen approach and how to embed the found system into architectural practice. This includes the facilitation of digital fabrication, as provided by the digital crafts, and material
properties in the design process. The further integration and feedback of parameters of material, tectonic and derived properties (i.e. performance based data and the combinatorial effects of compound materials and elements) through integrated simulations or rules of thumb into the design opens up new design possibilities.

Besides this the project is pointing at the changes in the profession (Kolarevic 2005), wherein architects become toolmakers. Customized tools help to materialize complex designs and enable a new design practice. This practice might find better ways of communicating to clients and environment as it is based on the negotiation of rules and parameters rather than images.

A close collaboration between the realm of architects and the digital craft will help to gather a better understanding of the overall possibilities. These have to be examined throughout – demonstrators will help to gather insights on all levels (Larsen 2008).

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